EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EPS95 Ref. **EPS-0406**
Submitted to **Pa-14 Pl-11**

29^{nd} June 1995

Evidence for strange b baryon production in Z decays

The ALEPH Collaboration

Abstract

In a total sample of 3,450,000 hadronic Z decays collected with the ALEPH detector from 1990 to 1994, an excess of 22.5 ± 5.7 events containing a correlated pair $\Xi^{\pm} l^{\pm}$ (where the lepton can be either an electron or a muon) is observed as compared to $\Xi^{\pm} l^{\mp}$ correlations in the same hemisphere of an event. This 4 standard deviation excess is interpreted as coming from the decay of strange b baryons, produced in Z decays , with a product branching ratio :

$$Br(b \to \Xi_b) \times Br(\Xi_b \to \Xi^{\pm} l^{\pm} \overline{\nu_l} X) = (5.3 \pm 1.3(stat) \pm 0.7(syst)) \times 10^{-4}$$

per lepton species, averaged for electrons and muons.

Contribution to the International Europhysics Conference on High Energy Physics, Brussels, Belgium, July 1995

OPEN-99-071
27/07/95

1 Introduction

Indirect evidence for Λ_b baryons has been found in Z decays by several LEP experiments, using events with Λl^- or $\Lambda_c^+ l^-$ correlations as the signature of b baryon semileptonic decays[1].

First indications of the strange b baryon Ξ_b have been also obtained at LEP, but with marginal statistical significance [2].

This note describes the search for strange b-baryons through $\Xi^\pm$ lepton correlations in 3,450,000 Z hadronic decays collected in 1990-94 by the ALEPH experiment.

2 Origin of Ξ-lepton correlations in hadronic Z decays

$\Xi^\pm$ lepton correlations are expected from the semileptonic decay of strange b-baryons. From simple spectator diagrams, one expects the following decays :

1. $\Xi_b^- \to \Xi_c^0 l^- \overline{\nu_l} X$, $\Xi_c^0 \to \Xi^- X^+$
2. $\Xi_b^0 \to \Xi_c^+ l^- \overline{\nu_l} X$, $\Xi_c^+ \to \Xi^- X^{++}$.

The signature of Ξ_b[1] decays is therefore a same sign $\Xi^\pm l^\pm$ pair. Hence, same sign correlations from Ξ_b baryons will be considered as "the signal".

Besides $\Xi^\pm l^\pm$ pairs from Ξ_b baryon semileptonic decays, several processes can contribute to $\Xi^\pm$ lepton combinations in hadronic Z decays. These processes are :

1. $b \to (\Lambda_c^+, \Xi_c^0) X l^- \overline{\nu_l}$, $followed\ by\ (\Lambda_c^+, \Xi_c^0) \to \Xi^- X$
2. $b, c \to \Xi_c^0 \to \Xi^- l^+ \nu_l$
3. Accidental correlations : e.g. true Ξ from string fragmentation and true lepton from the semileptonic decay of b or c particles ; fake or true Ξ and fake or true lepton.

Process (1) leads to $\Xi^\pm l^\pm$ combinations like the signal from Ξ_b semileptonic decays while process (2) leads to opposite sign $\Xi^\pm l^\mp$ combinations. Accidental correlations are expected to contribute nearly equally to $\Xi^\pm l^\pm$ and $\Xi^\pm l^\mp$ combinations, as confirmed by Monte Carlo studies.

3 Search for Ξ-lepton correlations in ALEPH data

The ALEPH detector properties have been described in [3]. The present analysis uses all data taken from 1990 to 1994. In the present study a total of 3.45 10^6 hadronic Z decays.

[1]Throughout this note Ξ_b is used as a generic name for Ξ_b^0 and Ξ_b^-. Charge conjugate reactions are also implied.

Specific simulations of the decay channels described above have been done for the reconstruction efficiency determination. Simulation studies of accidental correlations have been performed using $q\overline{q}$ Monte Carlo events, equivalent to about 3 times the data sample. Background studies on Ξ^- coming from fragmentation and leptons from B-mesons have been done on specific Monte Carlo productions equivalent to about 10 times the data sample, using the last version (7.4) of the JETSET program (ref [4]) .

3.1 Lepton and Ξ selection

The first stage in this analysis is particle identification.

Leptons in hadronic Z decays are identified in the ALEPH detector [3] using the standard procedure described in [5].

The Ξ^- are identified through the decay chain $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$. The $\Lambda \to p\pi^-$ selection is based on secondary vertices V^0, identified using the algorithm described in [6]. The Λ candidates coming from this algorithm are selected according to the following criteria :

- χ^2 of the V^0 vertex fit less than 10
- The distance between the V^0 vertex and the interaction point must be greater than 5 cm
- The V^0 momentum is required to be greater than 2.5 GeV/c

The Λ candidates are combined with a pion to build a Ξ^- candidate as follows :

- Λ and π^- with the right charge combination should be in the same hemisphere
- Probability of the χ^2 of the $\Lambda\pi^-$ vertex fit greater than 0.01
- The momentum of the $\Lambda\pi^-$ system must be greater than 3 GeV/c
- The Λ decay length must be positive and the $\Lambda\pi^-$ decay length, calculated with respect to the beam position, must be greater than 1.5 cm
- The transverse momentum of the pion P_t with respect to the $\Lambda\pi^-$ system must fulfil the condition $0.09 < P_t < 0.2$ GeV/c
- The longitudinal momentum of the $\Lambda\pi^-$ system, with respect to the event thrust axis, must be greater than 2 GeV/c

3.2 Selection of the Ξ-lepton pair

The candidate Ξ surviving the cuts described above are combined with identified leptons with momentum P $>$ 3 GeV/c ; they must belong to the same hemisphere defined with respect to the event thrust axis. The Ξ-lepton system is then required to satisfy the following cuts :

- The angle between the Ξ and the lepton candidates must satisfy $\theta_{\Xi l} < 45°$
- The invariant mass of the Ξ-lepton system must fulfil the condition :

$$2.5 < m_{\Xi l} < 5.0 \text{ GeV/c}^2$$

  The opposite sign $\Xi^{\pm} l^{\mp}$ pairs coming from charmed hadrons decays are almost completely eliminated by this cut .

Fig 1.a and 1.b give the $\Lambda\pi^-$ invariant mass distribution for the events with a Ξ-lepton pair selected as above, for the same and opposite sign combinations. A peak is seen in both distributions, which after fitting gives an invariant mass $m_{\Lambda\pi} = 1.321 \pm 0.004$ GeV/c^2 which is perfectly compatible with the standard Ξ mass [7]. Fig 1.a shows a clear excess of events in the same sign $\Xi^{\pm} l^{\pm}$ pairs, with respect to the opposite sign distribution, in the Ξ invariant mass peak defined by the condition :

$$1.28 < m_{\Lambda\pi} < 1.36 \text{ Gev/c}^2$$

It has been verified that the number of events in that mass region are shared between muon candidates and electron candidates, according to the proportions predicted by the muon and electron reconstruction efficiencies.

3.3 Use of a discriminating function x_{eff}

The remaining opposite sign pairs (Fig 1.b) are the accidental correlations described in Sec. 2 ; they are a good measurement of the fraction of same sign pairs coming from accidental correlations. This fraction (around 30%) is still important. To obtain a better Ξ_b purity, one can use a discriminating function x_{eff} as described in [8]. x_{eff} is build as follows :

- From Monte-Carlo studies, the following variables are chosen to allow a good discrimination between the signal and the background
  1. $m = m_{\Xi l}$, the Ξ-lepton invariant mass ,
  2. p_l , the longitudinal momentum of the Ξ with respect to the event thrust axis ,
  3. p_t , the transverse momentum of the lepton with respect to the direction of the jet it belongs to .
- The distribution of these variables is determined from the whole sample of Monte Carlo data described in Sec. 3 , for the Ξ_b signal and for the background. These distributions are fitted by a set of functions, and normalised to unity to give density functions for the three above variables. These functions are noted $g^s(m), g^s(p_l), g^s(p_t)$ for the signal $g^b(m), g^b(p_l), g^b(p_t)$ for the background.
- A global background fraction, η, is defined as the fraction of background events in the same sign data sample. From Monte Carlo studies, it is 25%. This value is also favoured by a likelihood fit to the data.

- The x_{eff} discriminating function is defined as follows , from [8] :

$$x_{eff} = \frac{\eta g^b(m) g^b(p_l) g^b(p_t)}{(1-\eta) g^s(m) g^s(p_l) g^s(p_t) + \eta g^b(m) g^b(p_l) g^b(p_t)}$$

Ideally, this discriminating function x_{eff} is peaked around 0 for the signal and around 1 for the background. Keeping only events with a low x_{eff} value allows to obtain a sample of Ξ_b candidates with a better purity and the maximum possible efficiency. Fig 1.c and 1.d give the $\Lambda\pi$ invariant mass distributions for the same sign and opposite sign Ξ lepton pairs which fulfil the condition $x_{eff} < 0.1$. The opposite sign combinations have been almost completely eliminated. After this cut the $\Xi_b \to \Xi^- l^- \overline{\nu_l} X$ detection efficiency, estimated from Monte Carlo JETSET 7.4 simulation is $\epsilon_{\Xi_b} = (2.2 \pm 0.25)\%$, not including the branching ratios of the Ξ^- decay chain .

Using the whole sample of simulated data described above, which in total is equivalent to about 10 times the real data sample, one finds that the number of opposite sign accidental Ξ-lepton pairs is compatible, within the available statistics, with the number of same sign accidental pairs. Therefore one can subtract the $\Xi^\pm l^\mp$ experimental distribution from the $\Xi^\pm l^\pm$ one, to get rid of accidental correlations. In the experimental distributions of Fig 1.c and 1.d if one takes only the events which fulfil the Ξ mass condition defined in Sec. 3.2, the subtraction of opposite sign events from same sign events gives :

$$\text{N } (\Xi^\pm l^\pm) \text{ - N } (\Xi^\pm l^\mp) = 28 \text{ - } 4 = (24 \pm 5.7\ ) \text{ events}$$

4 Ξ_b baryon production rate

4.1 Contribution of other b-hadrons

The number of events obtained above doesn't contain any more contributions of the accidental Ξ-lepton pairs. However, contributions from the decay of b-hadrons other than Ξ_b, as described in Sec. 2, may still remain. They must be subtracted to obtain an estimate of the number of Ξ_b candidates. These contributions are summarised in Table 1 and have been estimated in the following way :

- The probability $P(b \to \Xi^\pm l^\pm)$ has been computed from measured values when available. The following values have been used :

  1. $Br(b \to \Lambda_b^0) \times Br(\Lambda_b^0 \to \Lambda_c^+ l \nu X^-) = (1.51 \pm 0.3) \times 10^{-2}$ from ref[10]
  2. $Br(\Lambda_c^+ \to \Xi^- K^+ \pi^+) = (3.8 \pm 1.2) \times 10^{-3}$ from ref[7]
  3. $Br(B^+ \to \Xi^- X) = (2.7 \pm 0.6) \times 10^{-3}$ from ref[7]

- When no experimental value is available , the one coming from JETSET 7.4 is used

From Table 1, one deduces that the total contribution of Λ_b baryons and B-mesons to the observed number of same sign Ξ-lepton correlations, is at most 1.5

events with the cuts presently used. However this number is poorly known, since all possible decay channels giving Ξ-lepton final states are not measured. Therefore in the estimation of systematic errors, the above number of non Ξ_b contributions will be considered as known within a factor of 2.

Subtracting the estimated contribution of non Ξ_b pairs gives the final number :

$$\mathrm{N}\ (\Xi_b \to \Xi^{\pm} l^{\pm}) = (22.5 \pm 5.7)\ \text{events}$$

This is therefore a 4 standard deviation evidence for the production of strange b baryons in Z decays .

4.2 Systematic errors

As this measurement is still statistically limited, only two large contributions to the systematic error have been considered :

1. the accuracy on the reconstruction efficiency due to the limited statistics of the Monte-Carlo simulation
2. the contribution of b-hadrons other than Ξ_b, which is varied by 100% as described above

Other possible contributions to the systematic error e.g. the effect of the possible polarisation of the Ξ_b baryon (it is not polarised in the simulation) have not been considered yet.

4.3 Ξ_b production rate

Assuming the probability of having a $Z \to b\bar{b}$ decay to be 0.219 ± 0.006 from [9], the resulting production rate of Ξ_b baryons decaying into same sign Ξ-lepton pairs is :

$$Br(b \to \Xi_b) \times Br(\Xi_b \to \Xi^{\pm} l^{\pm} \overline{\nu_l} X) = (5.3 \pm 1.3(stat) \pm 0.7(syst)) \times 10^{-4}$$

per lepton species, averaged for electrons and muons. This result is statistically compatible with the numbers given in [2], with a much better accuracy.

5 Conclusion

A search for a correlation between a $\Xi^{\pm}$ and a lepton (electron or muon) of the same electric charge in the same event hemisphere has been done in hadronic Z decays. In a sample of 3,450,000 hadronic Z decays, an excess of 22.5 ± 5.7 events is found with same sign $\Xi^{\pm} l^{\pm}$ correlation with respect to events with opposite sign $\Xi^{\pm} l^{\mp}$ correlation. This significant excess is interpreted as coming from semileptonic decays of strange b-baryons and can be translated into the following product of branching fractions :

$$Br(b \to \Xi_b) \times Br(\Xi_b \to \Xi^{\pm} l^{\pm} \overline{\nu_l} X) = (5.3 \pm 1.3(stat) \pm 0.7(syst)) \times 10^{-4}$$

per lepton species, averaged for electrons and muons.

References

[1] ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. B **278**, (1992) 209.
ALEPH Collaboration, D. Buskulic *et al.*, Phys. Lett. B **294**, (1992) 145.
DELPHI Collaboration, P. Abreu *et al.*, Phys. Lett. B **311**, (1993) 379.
OPAL Collaboration, P. D. Acton *et al.*, Phys. Lett. B **281**, (1992) 394.

[2] ALEPH Collaboration, D. Decamp *et al.*, Contribution to the 27th ICHEP , Glasgow, Scotland, 20-27 July 1994, Contributed Paper n. 0603.
DELPHI Collaboration, P. Abreu *et al.*, CERN-PPE/95-29 (1995)

[3] ALEPH Collaboration, D.Decamp *et al.*, Nucl. Instr. and Meth. A **306**, (1991) 446.

[4] T. Sjöstrand and M. Bengtson, Comput. Phys. Commun. **46**, (1987) 43.

[5] ALEPH Collaboration, Nucl. Instr. and Meth. 4**346**, (1994) , 461 .

[6] ALEPH Collaboration, D. Buskulic *et al.*, Z. Phys. C**64** (1994) , 361 .

[7] Particle Data Group, Phys. Rev. D **50**, 1173 (1994) .

[8] D.Jaffe, F. LeDiberder and M-H Schune , LAL 96-67 and FSU-SCRI-94-101 , to be published in Nucl. Instr. and Meth. A .

[9] ALEPH Collaboration, D. Buskulic *et al.*, Z. Phys. C**62** (1994) , 179 .

[10] ALEPH Collaboration, D. Buskulic *et al.*, CERN-PPE/95-65 (1995).

Decay		$P(b \to \Xi^{\pm} l^{\pm})$	$\epsilon_{recons.}(\%)$	$N_{expect.}$
$\Lambda_b \to$	$\Lambda_c^+ l^- \bar{\nu}_l$ $\hookrightarrow \Xi^- K^+ \pi^+$	$(5.7 \pm 1.7)\ 10^{-5}$	0.9 ± 0.09	0.5 ± 0.2
$\Lambda_b \to$	$\Xi_c^0 X^+ l^- \bar{\nu}_l$ $\hookrightarrow \Xi^- X$	$\leq 1.2\ 10^{-4}$	0.7 ± 0.08	≤ 0.7
$B_s \to$	$(\Lambda_c^+ \ /\ \Xi_c^0) X l^- \bar{\nu}_l$ $\hookrightarrow \Xi^- X$	$\leq 5.0\ 10^{-5}$	0.07 ± 0.01	≤ 0.1
$B_{u,d} \to$	$(\Lambda_c^+ / \Xi_c^0) X l^- \bar{\nu}_l$ $\hookrightarrow \Xi^- X$	$(4.8 \pm 2.5)\ 10^{-5}$	0.05 ± 0.01	0.25 ± 0.1

Table 1: The expected fraction of $\Xi^{\pm} l^{\pm}$ correlations and expected number of detected events from semileptonic decays of b-hadrons other than Ξ_b baryons.

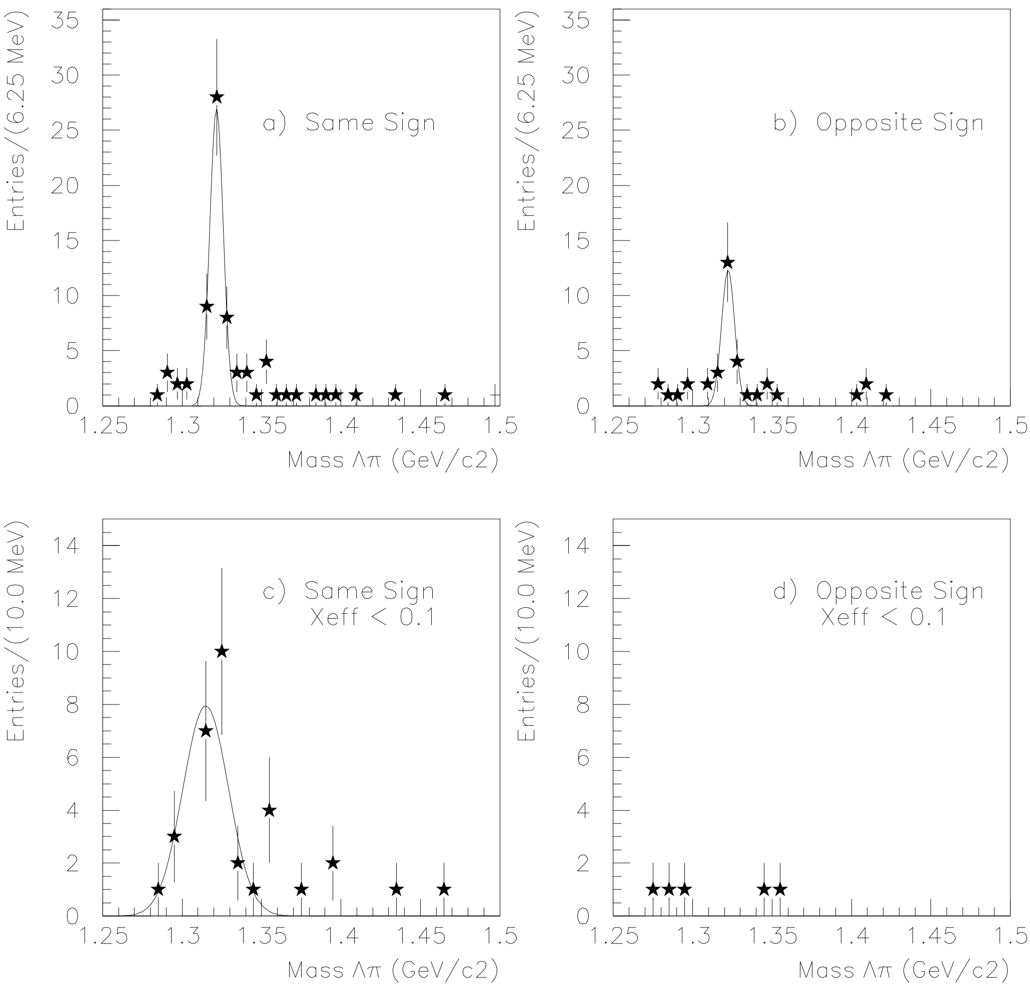

Figure 1: $\Lambda\pi$ invariant mass distributions for same and opposite sign Ξ lepton candidates . a) and b) correspond to the cuts described in Sec. 3.1 and 3.2 , c) and d) to the events selected with the discriminating function x_{eff} as described in Sec. 3.3.